Fatal Run off the Road Crashes on Rural Two-Lane Two-Way Highways in Minnesota

A Report Prepared

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Executive Summary

Every year, over 70 people are killed when vehicles depart two-lane two-way highways in Minnesota. This represents nearly 20% of all roadway fatalities each year. In addition to these fatalities, over 4,000 people are injured every year in these types of crashes. This study aims to determine the nature of the high number of run-off-the road fatal crashes on two-lane two-way highways. Despite the high numbers of people who are killed in run-off-the-road crashes, there seems to be little awareness from the general public about the scale of the problem.

This study is intended to provide a detailed look at run off the road crash problems. The analysis provided should assist transportation officials and other highway departments with facts and figures to help the general public understand the scope of the issue, and the tools that engineers are using to help mitigate this problem. This is especially the case with rumble strips, which have received some public feedback against their use due to the auditory noise they produce when hit. However, as highlighted in this study, rumble strips are one of the most effective and low cost countermeasures for mitigating run-off-the-road crashes. National and statewide studies have shown that rumble strips can reduce fatal and serious injury crashes by 17%-40%.

The Minnesota Department of Transportation (MnDOT) reviewed 338 fatal run-off-the-road (ROR) crashes on Minnesota two-lane two-way highways. These crashes resulted in the deaths of 365 people from 2009-2013. Analyses of crash records found that 197 crashes were the result of drivers drifting off of the roadway, and 141 crashes was the result of the driver losing control of the vehicle. Based on this information, it appears that behaviors such as inattention and distraction (associated with drifting off the roadway), and driving too fast for the conditions (associated with losing control of the vehicle) are both contributing significantly to the overall problem.

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Methodology

This study aims to understand the contributing factors of fatal run-off-the-road crashes on two-lane two-way highways and the relationship with traffic volume, roadway geometry such as horizontal curvature, weather factors, and other contributing factors.

Run-off-the-road crashes occur when a vehicle departs the lane of travel (the roadway surface) and impacts objects on the roadside or rolls over causing damage to the vehicle or injury to the occupants. After the crash, police officers filing the crash report determine the events of the crash by examining evidence, speaking with witnesses and those involved in the crash, and reviewing the crash scene. The direction of the run-off-the-road is determined by the vehicles final location in relation to its original intended path.

For these purposes, run-off-the-road crashes were limited to those in which one vehicle departed the roadway surface either to the right or to the left. These analyses were limited to fatal crashes. These analyses include crash records for January 1, 2009 through December 31, 2013. Other limitations included; only fatal crashes were reviewed, only crashes on two-lane two-way roadways, and only crashes that involved a single vehicle.

The primary contributing factors were determined using the crash report; which included items such as the police narrative, contributing factors 1 and 2 (the crash report allows officers to select two separate pre-defined factors that contributed to the crash occurring), vehicle pre-crash maneuvers, and apparent physical condition of the driver in the crash. These items informed the primary and secondary contributing factor, the true direction(s) of departure, objects that the vehicle collided with, and the nature of the sequence of events leading to the crash. Using information from the crash report, crashes were assigned to one of two primary contributing factors: drifting over the edgeline, and losing control (which includes weather-related factors). Other contributing factors or factors of interest included speeding, alcohol use, inattention, sleeping, rollovers, vehicle fire, hitting objects, and the presence of horizontal curves. Three-hundred thirty eight (338) crashes fit the selection criteria.

Findings

Run-off-the road crashes account for 17% of all crashes and over 30% of the fatal crashes. Run-off-the-road (ROR) crashes can be severe, and when combining left and right road departure, these crashes are the most common deadly type of crash in Minnesota. Separately they are surpassed only by head-on and right angle crashes (Fatal Crashes: ROR-Left = 13.4%, ROR-Right = 16.7%, Head On = 19.8%, Right Angle = 21%). The primary contributing factor was defined based on whether the vehicle slowly departed the lane (drifting), or if the departure was rapid, sudden, and difficult for the driver to control once the events started. The determination was at the interpretation of the author based on the crash report. Three-hundred thirty eight (338) crashes fit the selection criteria. Table 1 shows the primary contributing factors for vehicles involved in a run-off-the-road crash.

Table 1: ***Primary Contributing Factor; vehicle action prior to a fatal run-off-the-road crash*** (2009-2013)

Description	Number of Fatal Crashes	Percent of Fatal Crashes
Drifting over edge line	197	58.3%
Loss of Control	141	41.7%
Total	**338**	**100%**

Source: Minnesota Crash Mapping Application (MnCMAT), June 2014.

The secondary contributing factors were determined based on the crash report and the officer narrative. Not all crashes had a secondary contributing factor. Secondary contributing factors will be defined as actions, events, or behaviors that led to the crash. The determination was at the interpretation of the author based on the crash report. Secondary contributing factors included speeding, alcohol use, inattention, sleeping, rollovers, vehicle fire, hitting objects, weather-related loss of control, and the presence of horizontal curves. Other factors that were collected are in Table 2.

Table 2: Secondary contributing factor for fatal run-off-the-road crashes on Minnesota two-lane two-way Highways (2009-2013)

Secondary Contributing Factors	Number of Fatal Crashes	Percent of Fatal Crashes
Rollover	189	55.9%
Horizontal Curve	166	49.1%
Alcohol use / Chemical Impairment	77	22.8%
Speed	41	12.1%
Weather Related	10	3.0%
Inattention/Sleeping*	8	2.7%
Other	31	9.2%
Total number of secondary contributing factors	**522**	**89.1%**

Source: MnCMAT, June 2014. Minnesota Department of Public Safety, Driver and Vehicle Services(DPS-DVS), June 2014. Note: These factors are not stand alone; one crash could have multiple secondary contributing factors. *This factor is likely under-reported.

Nearly all crashes had at least one secondary contributing factor, as reflected in Table 2 (89.1%). See Table 3 for a list of the number of crashes with the corresponding number of contributing factors.

These factors are not stand alone; one crash could have multiple secondary contributing factors. For example, an impaired driver could run-off-the-road in a horizontal curve, and the vehicle then rolled over (secondary contributing factors would be Chemical Impairment, Curve, and Rollover). “Other” factors in Table 2 included vehicular fire, police chases, motorcycle related, submersion into water, and intersection related.

Horizontal curves and the vehicle rolling over after the road departure are the largest contributing factors to a fatal run-off-the-road crash. Chemical impairment and speed are also important factors.

Table 3: Number of secondary contributing factors for fatal run-off-the-road crashes on Minnesota two-lane two-way Highways (2009-2013)

Number of Contributing Factors	**=>1 (Primary)**	**2**	**3**	**4**	**5**
Number of Crashes	338	301	159	53	9

Source: MnCMAT, June 2014. DPS-DVS, June 2014.

The importance of Table 3 highlights that there is not one sole problem, but many factors in fatal crashes. For example, Table 3 shows that 159 crashes had at least three contributing factors that led to the crash. This emphasizes the need for multiple types of strategies and disciplines to reduce these crashes.

When a vehicle departs the lane, it can go either right or left. Crash records indicated that vehicles can also go to the left, and then depart the lane to the right (or vice versa). Table 4 lists the number of fatal crashes and fatalities for the direction that the road departure occurred.

Table 4: Direction of departure for fatal run-off-the-road crashes on Minnesota two-lane two-way Highways (2009-2013)

Direction of Departure	**Fatal Crashes**	**Fatalities**	**Percent of Fatal Crashes**
Right	154	167	45.6%
Left	136	150	40.2%
Right then Left	28	28	8.3%
Left then Right	20	20	5.9%
Total Crashes	**338**	**365**	**100%**

Source: MnCMAT, June 2014. DPS-DVS, June 2014.

These data were analyzed to find differences between run-off-the-road right and run-off-the-road left crashes. After conducting a statistical paired sample *t*-test on Tables 1,2,5,6, and 7, it was found that none of the crashes and categorical groupings had a statistically significant difference between the vehicle crashing to the right or to the left. The paired sample *t*-test is a statistical technique that compares the mean of two groups or conditions. See Appendix F for more details.

Once a vehicle departs the lane, a series of events may increase the risk of injury or death. Vehicles hit objects such as trees, utility poles, embankments, structures, and other roadside hazards. Table 5 lists the items that the vehicle collided with and the numbers of those crashes.

Table 5: Items hit during departure of a fatal run-off-the-road crash on Minnesota two-lane two-way Highways (2009-2013)

Description of Item	**Fatal Crashes**	**Fatalities**	**Percent of Fatal Crashes**
Driveway/ Embankment	120	131	45.5%
Tree	83	89	31.4%
Utility Pole	17	19	6.4%
Bridge/Structure	10	12	3.8%
Submerged/Water	10	10	3.8%
Guardrail	5	6	1.9%
Culvert	5	5	1.9%
Other	14	17	5.3%
Total Crashes	**264**	**289**	**100%**

Source: MnCMAT, June 2014. DPS-DVS, June 2014.

The most common type of item that was hit is driveways and embankments on the roadside. Over 66% (80 of 120 fatal crashes) of vehicles that hit embankments, the vehicle would rollover before the vehicle would come to rest. When a vehicle rolls over, occupants within the vehicle can be seriously or fatally injured, especially when unbelted. Based on the number of rollovers after hitting the embankment, it would appear that hitting the embankment itself may not be the most serious part of the crash, but the likelihood of the embankment hit has of creating imbalance and having the vehicle roll over.

Roadway System Classification

The State of Minnesota has several different roadway system classifications. Roadway system classification is a tool used by engineers, planners, and elected officials that helps to design roadways and set expectations of how roadways will be used and operated. The Interstate, US Route, and Minnesota Trunk Highway network has been designed to connect large and distant areas of the state, move large vehicles, and move large volumes of traffic (Interstates were not included in these analyses because there are no two-lane two-way Interstates). The County State Aid System (CSAH) and County Road (CR) network has been designed to provide mobility for shorter (county-wide) trips, along with more direct access to businesses, residential developments, and mobility to communities within a county. Municipal and Township systems have largely been developed to provide access to residential, commercial, and agricultural uses.

Using these classifications, engineers and planners can understand which parts of the network are overused or underperforming compared to similar facilities, based on certain set performance measures. This can help to allocate resources and identify needed improvements.

When analyzing based on roadway system classification, 26% of the fatal run-off-the-road crashes occur on US and MN Trunk Highways. These two classification systems comprise less than 8% of all roadways in Minnesota.

When adding in the CSAH and CR system, these four roadway system classifications make up over 86% of the fatal run-off-the-road crashes on two-lane highways in Minnesota. These four classifications make up 40% of the total roadway miles in Minnesota.

Table 6: System Classification for fatal run-off-the-road crashes and fatalities on Minnesota two-lane two-way Highways (2009-2013)

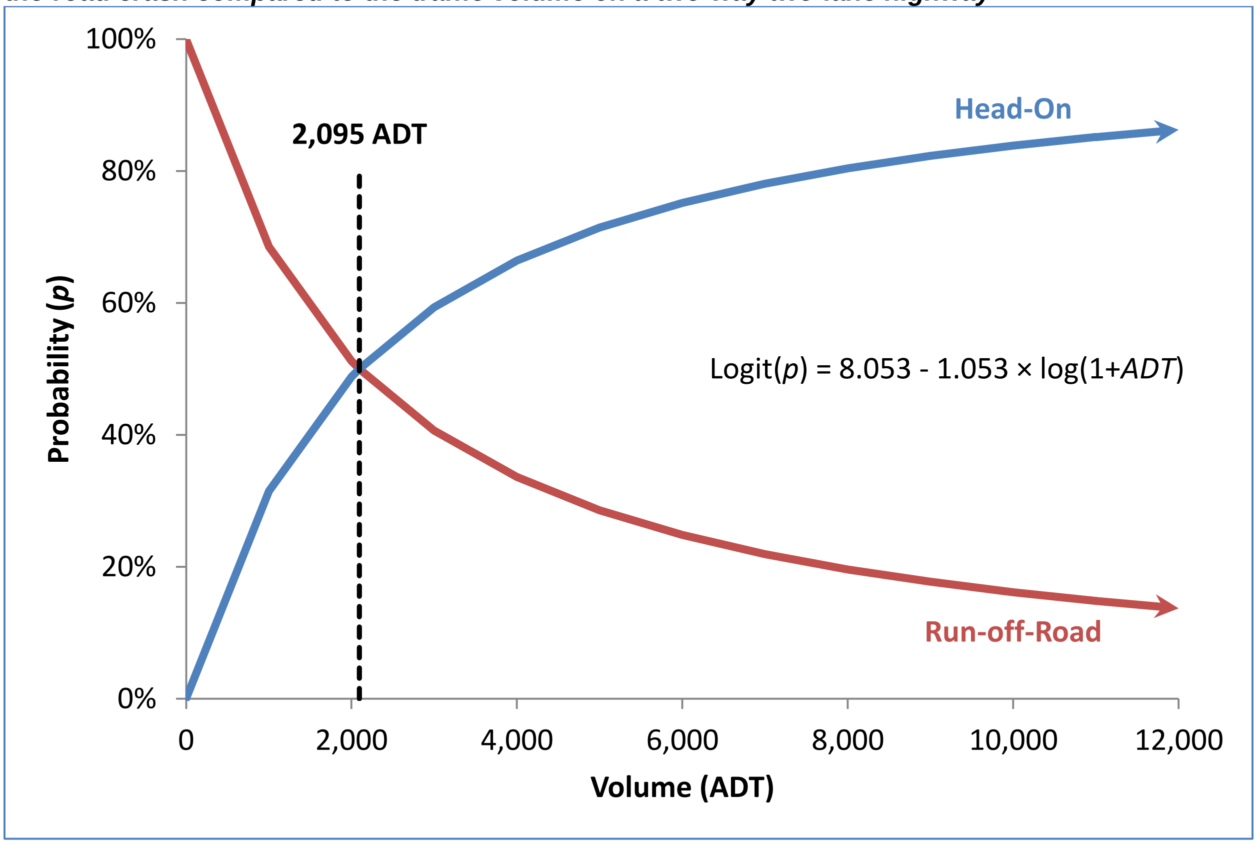
System Class	Number of Fatal Crashes	Number of Fatalities	Percent (%) of Total Fatal Crashes	Percent (%) of Total Minnesota System
US Route Trunk Highway	16	20	4.7%	2.3%
Minnesota (MN) Trunk Highway	71	75	21.0%	5.4%
County State Aid Highway (CSAH)	171	184	50.6%	21.5%
Municipal State Aid Highway (MSAS)	14	15	4.1%	2.6%
County Road (CR)	33	35	9.8%	10.0%
Municipal/Township/Other	33	36	9.8%	58.2%

Source: MnCMAT, June 2014. Note: These are sorted by the expected classification for the highways functionality, starting with those designed for mobility (US and MN Trunk Highways) and moving to those designed for access (municipal and township roads)

Traffic Volumes

The traffic volume of a roadway is an effective predictor of a run-off-the-road crash occurring. This study examined the traffic volumes to identify patterns between the fatal crashes and the corresponding traffic volume. As Figure 1 shows, there is a non-linear relationship between volume and fatal run-off-the-road crashes. Crash records were matched with the average daily traffic (ADT) of the roadway. See Appendix E for more information.

Figure 1: Logistical Regression estimating the probability of a fatal head-on crash or fatal run-off-the-road crash compared to the traffic volume on a two-way two-lane highway



Source: MnCMAT, June 2014. Minnesota Department of Transportation Office of Transportation Data and Analysis (MnDOT TDA), July 2014.

Traffic volumes were broken into categorical groups and each crash was placed into the appropriate grouping. Table 7 reveals the number of fatal crashes compared to the volume of the roadway. When the roadway miles are broken down to the same categories as the crash data above, Table 8 shows the following cataloged miles[1].

[1] MnDOT's Transportation and Data Analysis (TDA) keeps an inventory of most roads within Minnesota and their corresponding traffic volumes. The catalog includes nearly 59,000 miles of roadway. For more information regarding the data collection and methods used by TDA, the website is located at: http://www.dot.state.mn.us/traffic/data/coll-methods.html#TVPO

Table 7: Traffic Volumes (ADT) for fatalities in run-off-the-road crashes on Minnesota two-lane two-way highways (2009-2013)

Traffic Volume Range (ADT)	Number of Fatal Crashes	Number of Fatalities	Percentage of Total Fatal Crashes
0-200	38	41	11.2%
201-400	53	53	15.6%
401-1,000	108	122	31.8%
1,001-2,000	69	73	20.4%
2,001-3,000	27	29	8.0%
3,001 – 5,000	23	26	6.8%
5,001-10,000	13	13	3.8%
10,001-15,000	3	4	0.9%
15,001-20,000	4	3	1.2%
20,001+	1	1	0.3%
Total	**338**	**365**	**100.0%**

Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

Table 8: Number of miles of two-lane two-way highways in Minnesota, by traffic volume (ADT)

Traffic Volume Range (ADT)	Number of two-lane Miles	Percent of Cataloged Miles
0-400	29,336	51.4%
401-1,000	11,704	20.5%
1,001-2,000	6,925	12.1%
2,001-3,000	2,969	5.2%
3,001 – 5,000	3,091	5.4%
5,001-10,000	2,244	3.9%
10,001-15,000	550	1.0%
15,001-20,000	163	0.3%
20,001+	50	0.1%
Total	**57,034**	**100%**

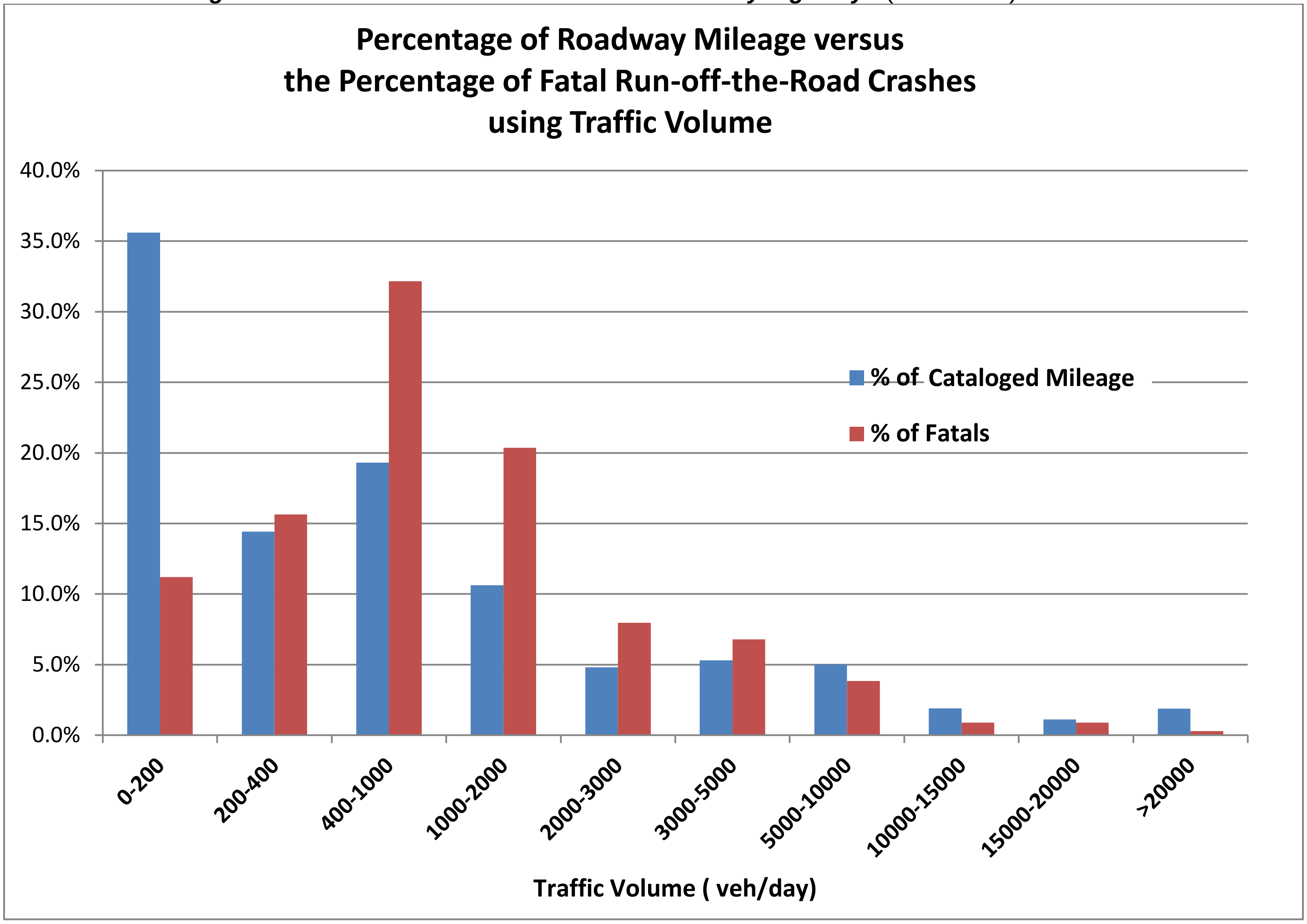
Source: MnDOT TDA, July 2014.

Comparing these two side by side is shown in Figure 2.[2]

Figure 2 shows that as the traffic volume rises above 2,000 veh/day, the percentage of fatal run-off-the-road crashes typically decreases.

[2] Minnesota has over 142,000 miles of roadway. The majority of the roadways not cataloged are owned by municipalities (>20,000 miles) and townships (>60,000 miles). These roads tend to have a low traffic volume (ADT<400 veh/day). These roadways would change Figure 2 to have a much higher percentage of roads with an ADT <400.

Figure 2: Percentage of roadway mileage versus the percentage of fatal run-off-the-road crashes when using traffic volume on Minnesota two-lane two-way highways (2009-2013)



Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

The analysis displayed in Figure 2 shows fatal run-off-the-road crashes are over represented on highways with a traffic volume between 200 vehicles/day and 5,000 vehicles/day, especially between 400 vehicles/day and 2,000 vehicles/day. Over 50% of the fatal run-off-the-road crashes, representing 195 people killed, occurred on 17,600 miles of roadway, 12.3% of the total statewide mileage.

US and MN Trunk Highways

The US & Minnesota Trunk Highway (TH) Network is managed by the Minnesota Department of Transportation (MnDOT) and accounts for less than 8% of the entire Minnesota roadway network, yet these roads carry over 40% of all the vehicle miles traveled. The information presented in this section is a subset of the information presented above.

Fatal crashes is weakly correlated with traffic volume (r = +0.239, p=0.063)[3]. Of the 95 people killed in run-off-the-road crashes on US and MN two-lane two-way Trunk Highways, 60% of fatalities (56 people) occurred on highways with traffic volumes below 2,000 ADT. These highways have a total length of 4,957 miles. See the Appendix F for more detailed information.

Table 9: Traffic Volumes (ADT) for fatalities in run-off-the-road crashes on Minnesota two-lane two-way Trunk Highways (2009-2013)

Traffic Volume Range (ADT)	Number of Fatal Crashes	Number of Fatalities	Percentage of TH Fatal ROR Crashes
0-400	4	4	4.6%
401-1,000	20	22	23.0%
1,001-2,000	28	30	32.2%
2,001-3,000	13	14	14.9%
3,001 – 5,000	9	11	10.3%
5,001-10,000	6	6	6.9%
10,001-15,000	3	4	3.4%
15,001-20,000	3	3	3.4%
20,001+	1	1	1.2%
Total	**87**	**95**	**100.0%**

Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

Table 10: Roadway miles of Minnesota two-lane two-way Trunk Highways by volume.

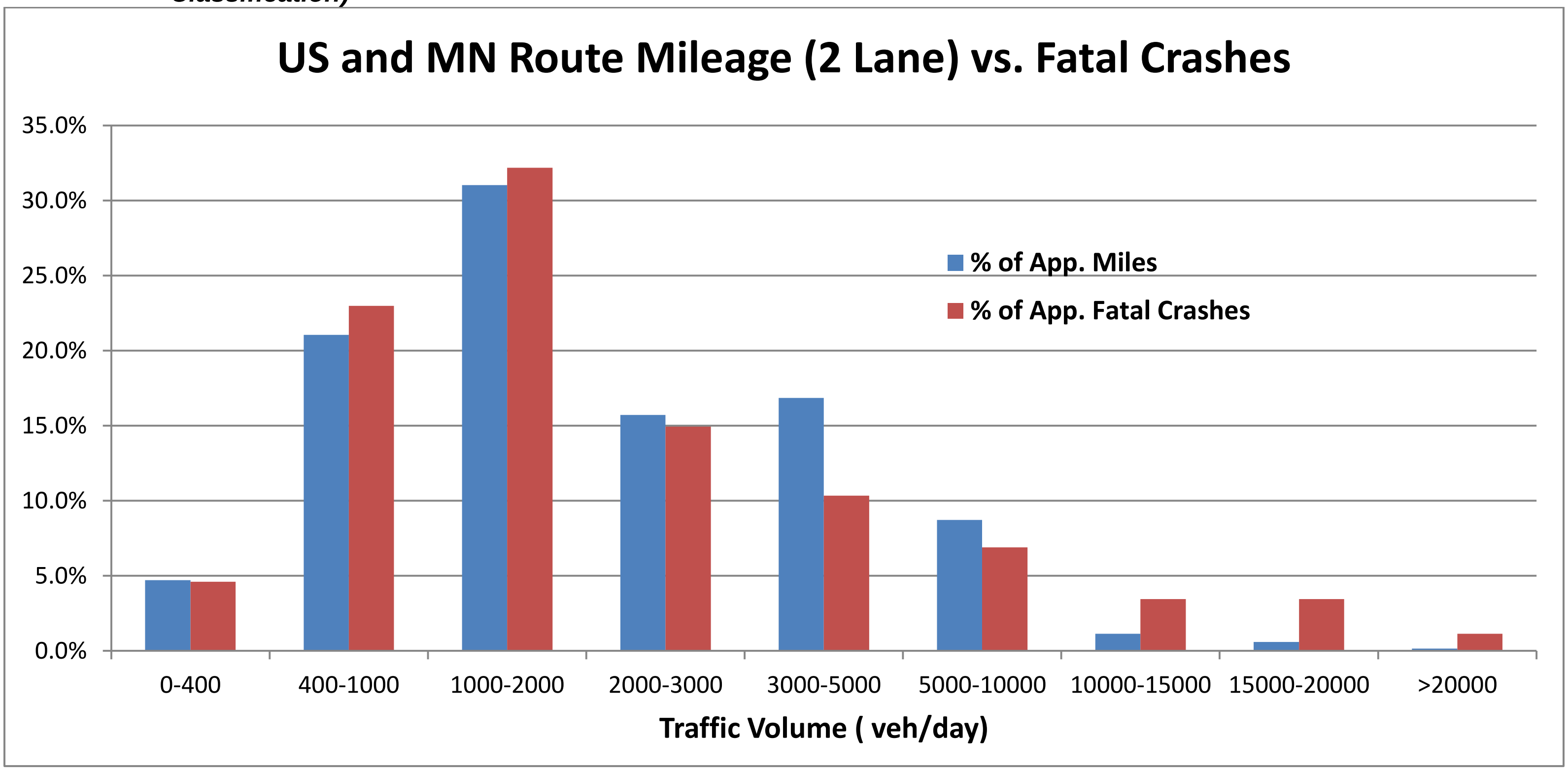
Traffic Volume Range (ADT)	Number of Miles	Percent of Miles
0-400	412	4.7%
401-1,000	1,838	21.1%
1,001-2,000	2,707	31.0%
2,001-3,000	1,372	15.7%
3,001 – 5,000	1,470	16.8%
5,001-10,000	762	8.7%
10,001-15,000	99	1.1%
15,001-20,000	52	0.6%
20,001+	14	0.2%
Total	**8,726**	**100%**

Source: MnDOT TDA, July 2014.

[3] The r value is a measure of how strong the factor contributes to the outcome, 1.0 being the cause and 0.0 having absolutely no influence in the outcome. The p value is a measure of the level of certainty in the analysis; 0.0 is absolute certainty and 1.0 has no certainty.

On US and MN two-lane two-way Trunk Highways with an ADT below 2,000 vehicles per day account for only 3.5% of the roadway miles in Minnesota, but account for nearly 5% of all traffic fatalities in a given year.

Figure 3: Percentage of trunk highway mileage versus the percentage of fatal run-off-the-road crashes when using traffic volume on Minnesota two-lane two-way Highways (US and MN Classification)



Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

Based on Figure 3, there does not appear to be one traffic volume group that is over-represented with fatal crashes. The connection between run-off-the-road fatalities on US and MN Trunk Highways and traffic volume alone does not stand out. Though the goal will always be zero fatalities in these figures, Figure 3 seems to show that traffic volume alone on US and MN routes is not contributing to these types of crashes. This might indicate that MnDOT has achieved a good balance between roadside design, maintaining clear zones, and providing a forgiving roadside on all roads, regardless of the traffic volume.

Strategies to Address Run-off-the-Road Crashes

The majority of fatal run-off-the-road crashes occur from drivers drifting or losing control of the vehicle and leaving the designated lane. An effort should be made to increase the visibility and awareness of each driver's respective lane. This includes:

Edgeline and Centerline Rumble Strips

Edgeline Rumble Strips are indentations that are milled into the pavement outside of the lane edge, or on the lane's white marking (formerly known as rumble stripEs). They provide immediate auditory and tactile lane departure warning to the driver as the vehicle approaches and crosses the edgeline. Edgeline rumble strips effectively reduce fatal and severe injury crashes by 17-36% (Torbic, et al. 2009. NCHRP Report 641). Edgeline Rumble Strips are one of the nine proven safety countermeasures according to the Federal Highway Administration (FHWA). Edgeline Rumble strips are a low cost strategy; current construction costs are roughly $3,000 per mile. Centerline Rumble Strips (CLRS) are also an important strategy, as they can mitigate the run-off-the-road left, head-on, and sideswipe crash problems. The fact that vehicles are just as likely to depart left as they are to depart right makes CLRS just as important as edge line rumble strips. Centerline Rumble strips are a low cost strategy; current construction costs are roughly $3,500 per mile The noise caused by vehicles that cross edge line and centerline rumbles can produce intermittent, noise that can impact residents proximal to centerline rumble strip installations. MnDOT is currently working to address this concern and is developing a rumble strip that produces less external noise.

6-8" Wide white edgelines

The typical pavement marking is 4" for the yellow centerline and the white edge line. Widening the pavement marking and/or using materials with higher retro-reflectivity (retro-reflectivity is a measure of how much light is reflected back to a driver from a sign or pavement marking) can help to provide increased delineation and guidance for drivers in dark and/or adverse weather conditions. Recent studies have found a 10% or greater crash reduction (Carlson et al, 2013 and Fleming, 2013) versus the control sites. The cost on the wider lines is around $800 per mile. Wider edge lines help drivers navigate the road, but provide no direct auditory or tactile feedback to alert the driver.

Clear Zone

The clear zone is defined as the area outside of the travel lane that should be kept clear of objects that are not breakaway or defined as crashworthy, and slopes should be traversable. Breakaway and crashworthy devices are those that have been designed and tested to reduce the chance for serious injuries or fatal crashes if impacted by an errant vehicle at high speeds. For most rural two-lane two-way highways, this zone ranges from 15'-40' outside of the lane. Removing objects in the clear zone can be politically charged at times due to the removal of trees, utility poles, and other residential objects. Creating clear zones can be difficult. However, this is important, especially on rural roads with traffic volumes above 400 vehicles/day. Recently, the FHWA has put a renewed emphasis on this strategy.

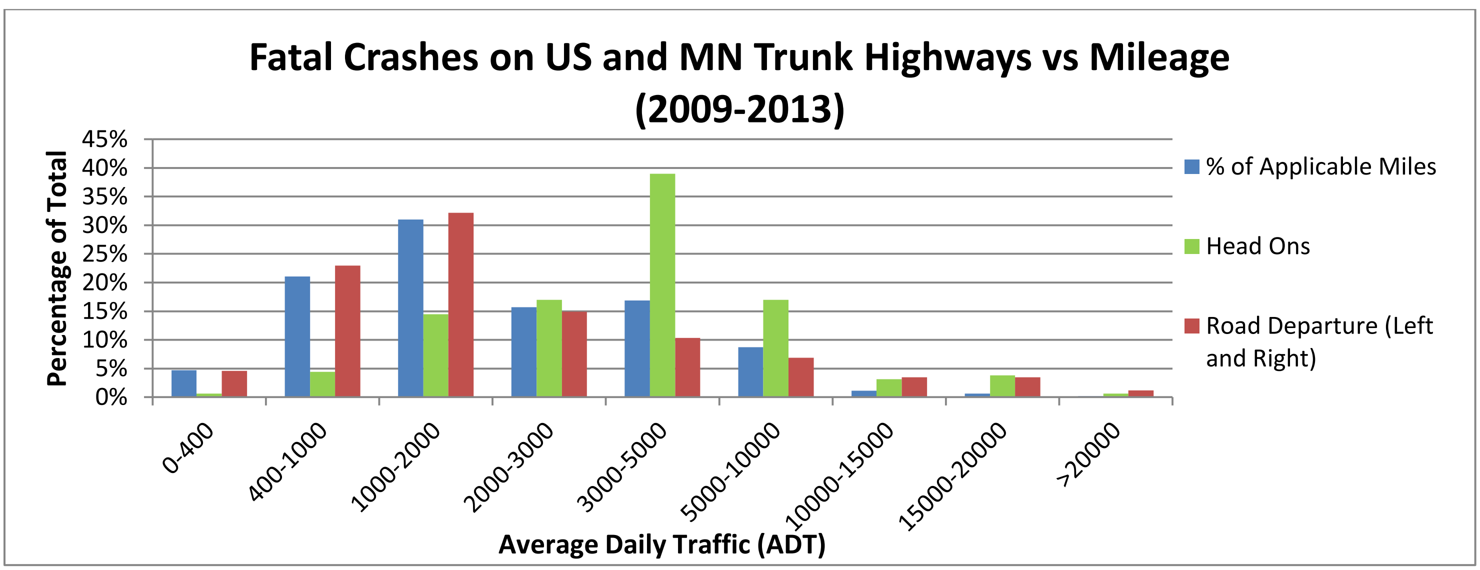
Paved or Gravel Shoulders

Shoulders on roadways can offer vehicles a safe place for refuge, and provide additional space for errant vehicles to recover. Research and the Highway Safety Manual have consistently shown that the wider a shoulder is on a roadway, typically the safer a roadway is, especially when corrected for other factors such as traffic volume and the geometric characteristics (horizontal curves, roadway alignments, and vertical grades). The material of the shoulder (asphalt, concrete, gravel, grass, etc.) does not appear to affect the overall number of crashes. Shoulder width appears to be the most important factor when looking at all crashes; the wider, the better.

Widening shoulders to roadways is costly. Recent projects completed and planned by MnDOT have ranged from $400,000 per mile to over $1,000,000 per mile (widening just two feet to adding a full eight feet). On most low volume roadways (<2,000 veh/day), the benefits are not enough to outweigh these types of costs.

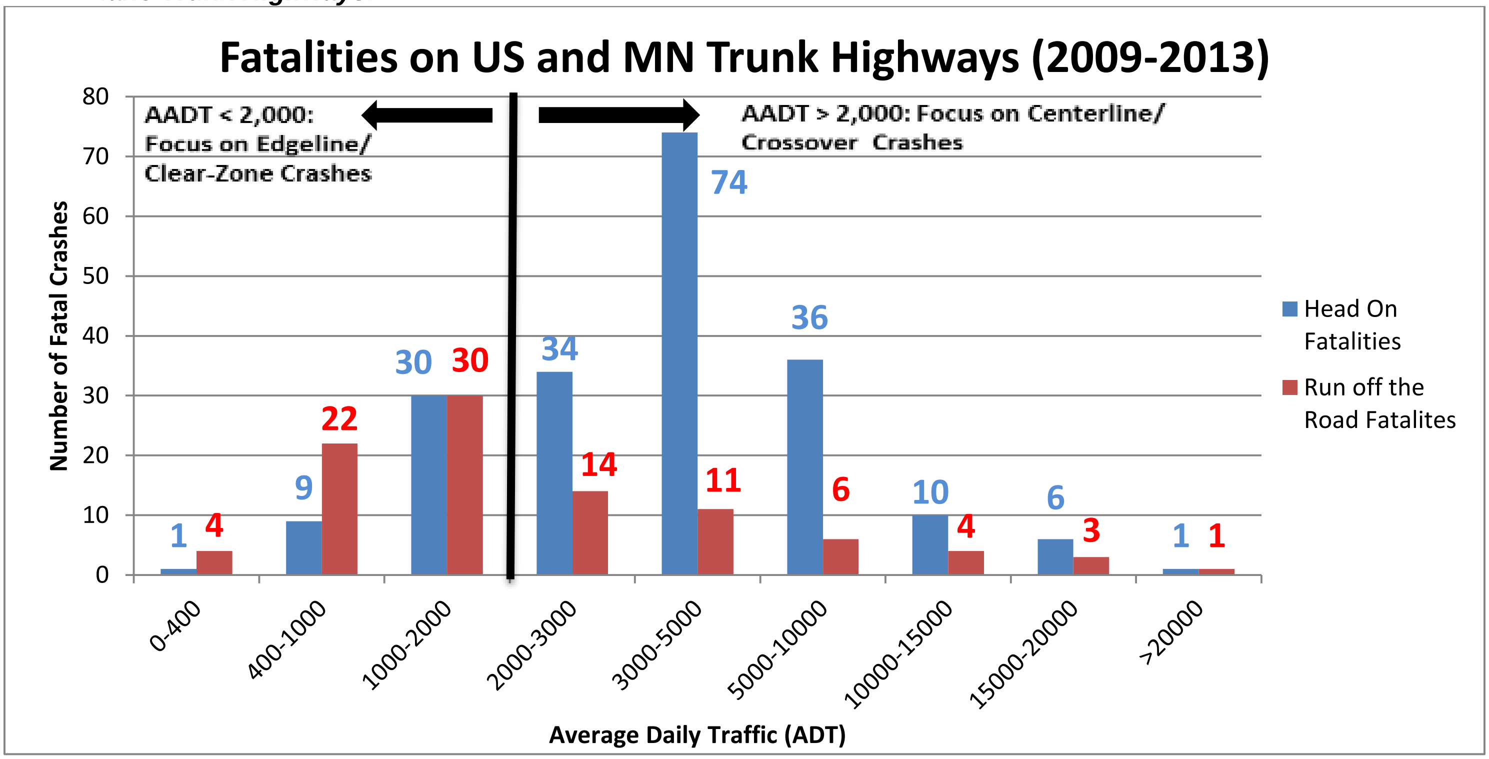
A wide surface outside of the lane may have little impact on the outcome of a ***fatal*** run-off-the-road crash. When examining the road departure crashes, there are nearly as many fatal run-off-the-road crashes to the left as there are to the right. What is interesting to note is that most shoulders (especially on the county system) are typically less than 4 feet in width to the right, and that drivers often have a 12 foot or greater shoulder to the left (the opposing lane and shoulder when unoccupied), yet despite this wide surface, the total number of fatal crashes is nearly identical. This appears to make a strong case against widening shoulders to mitigate ***fatal*** run-off-the-road crashes, but widening may be a good strategy to provide the buffer between two opposing lanes given the high number of fatal head-on crashes. (See the report "Fatal Head-On Crashes on Rural Two-Lane Two-Way Highways in Minnesota" by Derek Leuer)

Figure 4: A comparison of the percentage of US and MN two-lane two-way Highways by traffic volume versus the percentage of fatal head-on crashes and the percentage of fatal road departure crashes.



Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

Figure 5: The number of each type of fatal crash versus traffic volume on US and MN two-way two-lane Trunk Highways.



Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

Edgeline Rumble Strips' Impact on Fatal Crashes

Each fatal run-off-the-road crash (during the study period) location on Minnesota Trunk Highways was examined to determine if a rumble strip was in place at the time of the crash. Examining rumble strip placements, seventy-five (75) of the 87 fatal run-off-the-road crashes (86%) occurred where no edgeline rumble strips were present at the time of the crash. A recent sampling found that between 2010 and 2013, edgeline rumbles increased from 28% of roadway miles to 50% of Minnesota's two-lane two-way trunk highways. With an equal mileage of highways with and without edgeline rumble strips, only 12 fatal crashes occurred where rumbles are present, and 75 occurred where there are not rumble strips.

When reviewing crash performance of roads with edgeline rumble strips (ELRS) versus those that do not have edgeline rumble strips in place, a difference is noted. See Table 11.

Table 11: A comparison of segments with and without edgeline rumble strips.

Description	Crash Rate With ELRS	Crash Rate Without ELRS	Difference
Fatal and Severe Crash Rates	2.13 Severe Crashes/ 100 Million Vehicle Miles Traveled	3.33 Severe Crashes/ 100 Million Vehicle Miles Traveled	**- 36.0%**
All Crashes Rate	0.57 Crashes/ 1 Million Vehicle Miles Traveled	0.69 Crashes/ 1 Million Vehicle Miles Traveled	**- 17.4%**

Source: OTST Toolkit, 2013.

Benefit to Cost of Implementing Rumble Strips

Before recommending edgeline and centerline rumble strips on US and MN trunk highways, County State Aid Highways and County Roads with an ADT above 400 vehicles per day, a benefit/cost ratio should be calculated. It is important to note that this is using only fatal crashes (all crashes will be calculated after). MnDOTs current Technical Memorandum No. 14-07-T-01 currently requires all Minnesota Trunk Highways with certain conditions install edge line or centerline rumble strips.

The recommendation on this page will be on all rural, two-lane two-way US and MN trunk highways, County State Aid Highways and County Roads with an ADT above 400 vehicles per day. See the Appendix A-D for more information.

Table 12*: Benefit/ Cost Ratios for certain system classifications and traffic volumes (ADT) > 400 for edgeline rumble strips based only on fatal crashes*

System Classification	Fatal Crashes – Run-off-the-Road Right (2009-2013)	Two-Lane miles remaining without ELRS& ADT >400 (estimated)	Benefit/ Cost Ratio
US and MN Trunks	32	4,450	1.8
CSAH	68	10,800	1.2
C.R.	9	1,000	1.7
Township / Other	8	~4,000	<0.4

Source: MnCMAT, September 2014. MnDOT TDA, July 2014. MN County Road Safety Plan (CRSP) Database, February 2015. MnDOT VideoLog 2013.

Table 13*: Benefit/ Cost Ratios for certain system classifications and traffic volumes (ADT) > 400 for centerline rumble strips based only on fatal crashes*

System Classification	Fatal Crashes – Run-off-the-Road Left (2009-2013)	Fatal Crashes – Head-On (2009-2013)	Two-Lane miles remaining without CLRS & ADT>400 (estimated)	Benefit/ Cost Ratio
US and MN Trunks	38	158	7,825	4.8
CSAH	57	72	10,800	2.1
C.R.	7	2	1,000	1.5
Township / Other	16	4	~4,000	<0.2

Source: MnCMAT, September 2014. MnDOT TDA, July 2014. MN County Road Safety Plan (CRSP) Database, February 2015. MnDOT VideoLog 2013.

a. *Assumptions*

Cost per Edgeline Mile: $3,000

Cost per Centerline Mile: $3,500

Installation of Edgeline Rumbles: 16,250 miles (On US, MN, CSAH, and CR with ADT>400)

Installation of Centerline Rumbles:19,625 miles(On US, MN, CSAH, and CR with ADT>400) *b.* *Costs*

Total Costs: ($3,000/ mile x 16,250 miles) + ($3,500/ mile x 19,625) = $117,500,000

-Total Cost on US and MN Trunk Highways:
($3,000/ mile x 4,450 miles) + ($3,500/ mile x 7,825) = $40,800,000

c. *Benefits*

Edgeline Crash Reduction Factor: 36%
(http://www.cmfclearinghouse.org/detail.cfm?facid=3454)

Centerline Crash Reduction Factor: 45%
(http://www.cmfclearinghouse.org/detail.cfm?facid=3360)

Life Expectancy of Rumbles: 7 Years (FHWA)

Reduction in Fatal Crashes: 36 fatal crashes per year x 7 years = 252 fatal crashes (this is based from the crashes from 2009-2013 and applying the appropriate crash modification factors; See Appendix B)

Societal Cost per Fatal Crash: 2 x Injury Type A = $1,100,000
(http://www.dot.state.mn.us/planning/program/appendix_a.html)

Societal Cost of Target Fatal Crashes on recommended roads (5 years):

System Classification	**Fatal Crashes – Run-off-the-Road Right (2009-2013)**	**Fatal Crashes – Run-off-the-Road Left (2009-2013)**	**Fatal Crashes – Head-On (2009-2013)**	**Total**
US and MN Trunks	32	38	158	**228**
CSAH	68	57	72	**197**
C.R.	9	7	2	**18**
Total	**109**	**102**	**232**	**443**

443 fatal crashes x $1.1M =$487,300,000

Societal Cost Savings (7 years): 252 fatal crashes x $1.1M = $277,200,000

d. *Benefit/Costs*

Total Benefit/ Total Cost: $277,200,000/ $117,500,000 = 2.36

Total Statewide Benefit/Cost Ratio adjusted for inflation = 2.14 (See Appendix B)

Total Benefit/Cost Ratio on US and MN Trunk Highways = 3.29 (See Appendix A)

Potential Fatal Crashes Prevented (7 years) = 252 fatal crashes (259-336 fatalities)

With the reduction to all crashes the B/C Ratio = 7.14 (See Appendix C for more details)

Recommendations

With the high number of fatal crashes on US and MN two-lane two-way Trunk Highways, it is recommended that all highways and county roads with a traffic volume greater than 400 vehicles per day should have edgeline ***and*** centerline rumble strips installed. County highways should follow these practices as well, especially with traffic volumes greater than 400 vehicles per day. Once all the rumbles are installed, there is potential to prevent around 36 fatal crashes each year. The societal crash savings from the fatal crashes have the potential to cover the $117.5 Million construction cost.

The reduced cost to society only considers the application of edgeline and centerline rumble strips. The addition of other traffic safety strategies (intersection illumination, placing chevrons on curves, etc.) could result in even greater reductions to societal costs by preventing fatal crashes. The Network of Employers for Traffic Safety (NETS) estimated that in the year 2000, the economic cost of crashes was over $60 billion and resulted in 3 million lost workdays to Employers across the United States.

In addition, $117.5 Million is a high estimated project cost. When rumbles are added to mill and overlay, rehabilitation, and reconstruction projects, the cost per mile is below the $3,000 - $3,500 per mile. The 2014 MnDOT Construction Bids averaged $0.15 per linear foot for rumble strips, or $1,600 per mile for edgeline or centerline rumbles strips. $117.5 Million constitute a sizable portion of MnDOT's overall construction budget, which often exceeds $1 Billion each year. Spread out over 5 years, the total cost would be less than 2.4% of the total construction budget per year.

Appendices

Appendices A: A Benefit/Cost ratio showing the reduction in fatal crashes only on two-lane two-way US and MN Trunk Highways with an ADT>400. The crash data is from 2009-2013.

HSIP worksheet

Control Section	T.H. / Roadway	Location	Beginning Ref. Pt.	Ending Ref. Pt.	State, County, City or Township	Study Period Begins	Study Period Ends
		All US and MN Trunk Highways, ADT > 400				1/1/2009	12/31/2013
Description of Proposed Work		Edgeline and Centerline Rumbles					

Accident Diagram Codes			1 Rear End	2 Sideswipe Same Direction	3 Left Turn Main Line	5 Right Angle	4,7 Ran off Road	8, 9 Head On/ Sideswipe - Opposite Direction	Pedestrian	6, 90, 99 Other	Total
Study Period: Number of Crashes	Fatal	F					70	158			228
	Personal Injury (PI)	A									
		B									
		C									
	Property Damage	PD									
% Change in Crashes *Use Crash Modification Factors Clearinghouse	Fatal	F					-36%	-45%			
	PI	A									
		B									
		C									
	Property Damage	PD									
Change in Crashes = No. of crashes X % change in crashes	Fatal	F					-25.20	-71.10			-96.30
	PI	A									
		B									
		C									
	Property Damage	PD									

Year (Safety Improvement Construction)	2015
Project Cost (exclude Right of Way)	$ 40,800,000
Right of Way Costs (optional)	$ -
Traffic Growth Factor	1%
Capital Recovery	
1. Discount Rate	4.5%
2. Project Service Life (n)	7

Type of Crash	Study Period: Change in Crashes	Annual Change in Crashes	Cost per Crash	Annual Benefit
F	-96.30	-19.26	$ 1,100,000	$ 21,186,000
A			$ 550,000	
B			$ 160,000	
C			$ 81,000	
PD			$ 7,400	
Total				$ 21,186,000

B/C= 3.29

Using present worth values,

B= $ 134,205,339

C= $ 40,800,000

See "Calculations" sheet for amortization.

Office of Traffic, Safety and Technology
September 2014

Appendices B: A Benefit/Cost ratio showing the reduction in fatal crashes only on two-lane two-way US and MN Trunk Highways, with an ADT>400. The crash data is from 2009-2013.

HSIP worksheet	**Control Section**	**T.H. / Roadway**	**Location**	**Beginning Ref. Pt.**	**Ending Ref. Pt.**	**State, County, City or Township**	**Study Period Begins**	**Study Period Ends**
			All US and MN Trunks, CSAH, and CR Highways, ADT > 400				1/1/2009	12/31/2013
Description of Proposed Work	Edgeline and Centerline Rumbles							

Accident Diagram Codes			1 Rear End	2 Sideswipe Same Direction	3 Left Turn Main Line	5 Right Angle	4,7 Ran off Road	8, 9 Head On/ Sideswipe - Opposite Direction	**Pedestrian**	6, 90, 99 **Other**	**Total**
Study Period: Number of Crashes	Fatal	**F**					211	232			**443**
	Personal Injury (PI)	**A**									
		B									
		C									
	Property Damage	**PD**									
% Change in Crashes *Use Crash Modification Factors Clearinghouse	Fatal	**F**					-36%	-45%			
	PI	**A**									
		B									
		C									
	Property Damage	**PD**									
Change in Crashes = No. of crashes **x** % change in crashes	Fatal	**F**					**-75.96**	**-104.40**			**-180.36**
	PI	**A**									
		B									
		C									
	Property Damage	**PD**									

Year (Safety Improvement Construction)	**2015**						
Project Cost (exclude Right of Way)	**$ 117,500,000**	**Type of Crash**	**Study Period: Change in Crashes**	**Annual Change in Crashes**	**Cost per Crash**	**Annual Benefit**	**B/C= 2.14**
Right of Way Costs (optional)	**$ -**	**F**	**-180.36**	**-36.07**	**$ 1,100,000**	**$ 39,679,200**	*Using present worth values,*
Traffic Growth Factor	**1%**	**A**			**$ 550,000**		**B= $ 251,352,804**
Capital Recovery		**B**			**$ 160,000**		**C= $ 117,500,000**
1. Discount Rate	**4.5%**	**C**			**$ 81,000**		*See "Calculations" sheet for amortization.*
2. Project Service Life (n)	**7**	**PD**			**$ 7,400**		
		Total				**$ 39,679,200**	**Office of Traffic, Safety and Technology September 2014**

Appendices C: A Benefit/Cost (B/C) ratio showing the effect of centerline rumble strips and edgeline rumble strips on all crashes on US, MN, CSAH, and CR two-lane two-way Highways.. The crash data is from 2009-2013.

HSIP worksheet	Control Section	T.H. / Roadway	Location	Beginning Ref. Pt.	Ending Ref. Pt.	State, County, City or Township	Study Period Begins	Study Period Ends
			All US and MN Trunks, CSAH, and CR Highways, ADT > 400				1/1/2009	12/31/2013
	Description of Proposed Work		Edgeline and Centerline Rumbles					

Accident Diagram Codes			1 Rear End	2 Sideswipe Same Direction	3 Left Turn Main Line	5 Right Angle	4,7 Ran off Road	8, 9 Head On/ Sideswipe -Opposite Direction	Pedestrian	6, 90, 99 Other	Total
Study Period: Number of Crashes	Fatal	F					211	232			443
	Personal Injury (PI)	A					453	310			763
		B					2021	811			2832
		C					2645	968			3613
	Property Damage	PD					8371	3543			11914
% Change in Crashes	Fatal	F					-36%	-45%			
	PI	A					-36%	-45%			
*Use Crash Modification Factors Clearinghouse		B					-36%	-45%			
		C					-36%	-45%			
	Property Damage	PD					-10%	-10%			
Change in Crashes	Fatal	F					-75.96	-104.40			-180.36
	PI	A					-163.08	-139.50			-302.58
= No. of crashes x % change in crashes		B					-727.56	-364.95			-1092.51
		C					-952.20	-435.60			-1387.80
	Property Damage	PD					-837.10	-354.30			-1191.40

Year (Safety Improvement Construction)	2015
Project Cost (exclude Right of Way)	$ 117,500,000
Right of Way Costs (optional)	$ -
Traffic Growth Factor	1%
Capital Recovery	
1. Discount Rate	4.5%
2. Project Service Life (n)	7

Type of Crash	Study Period: Change in Crashes	Annual Change in Crashes	Cost per Crash	Annual Benefit
F	-180.36	-36.07	$ 1,100,000	$ 39,679,200
A	-302.58	-60.52	$ 550,000	$ 33,283,800
B	-1092.51	-218.50	$ 160,000	$ 34,960,320
C	-1387.80	-277.56	$ 81,000	$ 22,482,360
PD	-1191.40	-238.28	$ 7,400	$ 1,763,272
Total				$ 132,168,952

B/C=	**7.13**

Using present worth values,

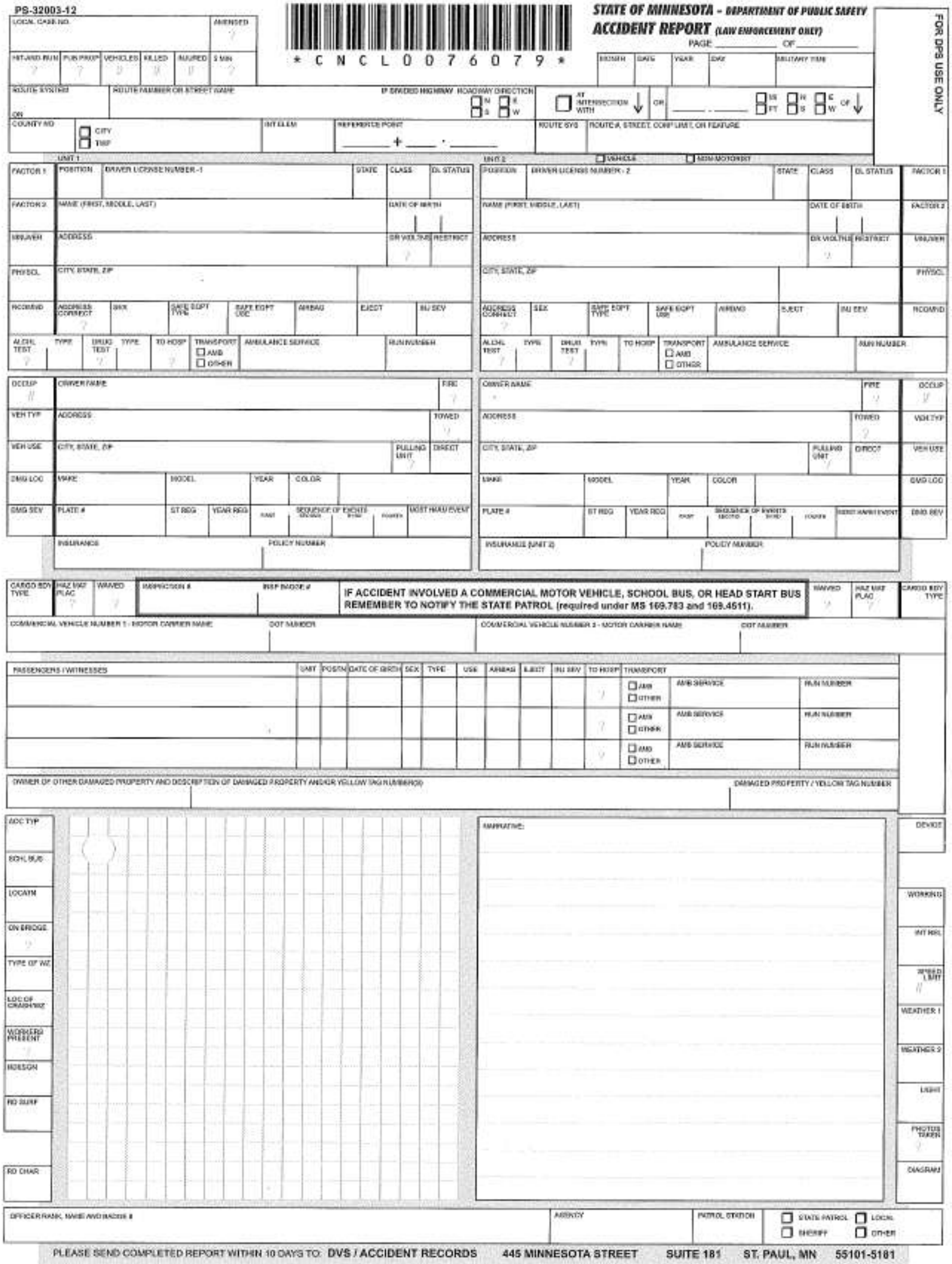
B= $ 837,240,586

C= $ 117,500,000

See "Calculations" sheet for amortization.

Office of Traffic, Safety and Technology
September 2014

Appendices D: An example of the crash report form used in Minnesota.


PS-32003-12

STATE OF MINNESOTA – DEPARTMENT OF PUBLIC SAFETY

ACCIDENT REPORT (LAW ENFORCEMENT ONLY)

PAGE ____ OF ____

FOR DPS USE ONLY

* C N C L 0 0 7 6 0 7 9 *

IF ACCIDENT INVOLVED A COMMERCIAL MOTOR VEHICLE, SCHOOL BUS, OR HEAD START BUS REMEMBER TO NOTIFY THE STATE PATROL (required under MS 169.783 and 169.4511).

PLEASE SEND COMPLETED REPORT WITHIN 10 DAYS TO: DVS / ACCIDENT RECORDS 445 MINNESOTA STREET SUITE 181 ST. PAUL, MN 55101-5181

Appendices E: Fatal Head-On / Run-off-Road Analysis

2009-2013 Trunk Highway Crashes

1. Logistic Regression

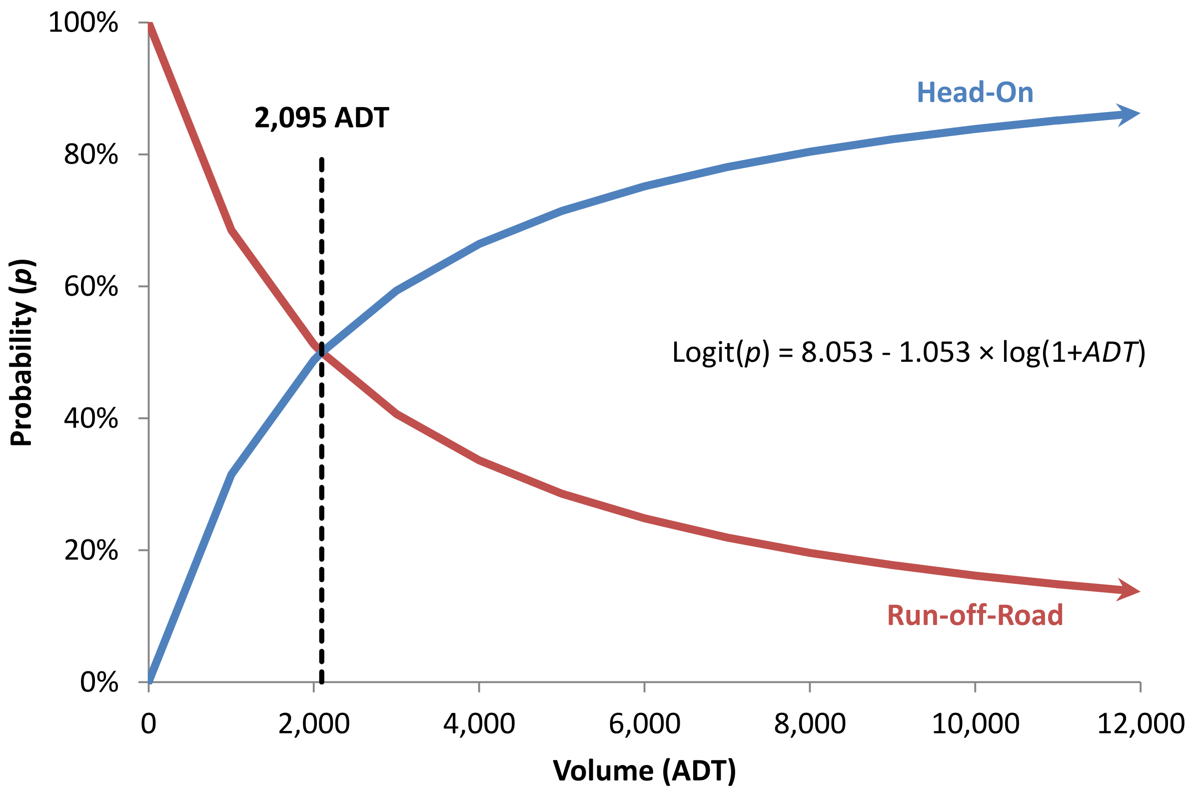
Logistic regression provides the likelihood of an event occurring given a defined environment. This examines the probability of a run-off-road crash among fatal lane departure crashes.

The model coefficients are estimates for the impact on the odds ratio. If the odds ratio is greater than 1, then run-off-roads are more likely than head-ons.

2. Model Estimates

Variable	Coefficient	Std. Error	Significance
[Constant]	8.053	.099	**.000**
Log ADT	-1.053	.744	**.000**

This model correctly classifies 77% of all fatal lane departure crashes by volume alone! On roads with an ADT of 2,095, fatal lane departure crashes have an equal likelihood being a head on or run-off-road crash. As the ADT increases the the likelihood that a fatal lane departure crash will be a head-on crash versus a run-of-road crash increases dramatically.



3. Comparison of Lane Departure to Volume

Using the derived model, there is a natural break-point where it is equally likely that a fatal lane departure will be head-on or run-off-road. This occurs at 2,095 vehicles.

Fatal lane departure crashes

ADT Range	Head-Ons		Run-off-Roads		Lane Departures
0 to 2,095	73	21%	272	79%	345
2,096 to	178	73%	66	27%	244

When roadway volume ranges from zero to 2,095, there are 3.7 times more RUN-OFF-ROAD fatal crashes than head-on; for roads over 2,095, there are 2.7 times more HEAD-ONs than run-off-road fatal crashes.

Appendices F: Statistical T-Test Results showing ROR-R versus ROR-L crashes.

INDEPENDENT SAMPLES TEST											
VARIABLES TESTED		Levene's Test for Equality of Variances			t-test for Equality of Means			Descriptive Statistics			
		Assumption Used	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference Lower	95% CI of the Difference Upper
Prior Action	Drifting over Centerline	Equal variances assumed	1.046	.307	-.523	288	**.601**	-.030	.058	-.145	.084
Prior Action	Loss of Control	Equal variances assumed	1.046	.307	.523	288	**.601**	.030	.058	-.084	.145
Second. Contr. Factor	Alcohol	Equal variances not assumed	6.546	.011	-1.272	287.827	**.204**	-.062	.049	-.158	.034
Second. Contr. Factor	Rollover	Equal variances assumed	1.643	.201	-1.481	288	**.140**	-.087	.059	-.203	.029
Second. Contr. Factor	Lost Control/Weather	Equal variances assumed	3.231	.073	.895	288	**.372**	.017	.019	-.021	.055
Second. Contr. Factor	Curve	Equal variances assumed	1.137	.287	-1.442	288	**.150**	-.085	.059	-.201	.031
Second. Contr. Factor	Inattention/Sleep	Equal variances not assumed	6.037	.015	-1.257	240.294	**.210**	-.019	.015	-.048	.011
Second. Contr. Factor	Speed	Equal variances assumed	1.813	.179	-.670	288	**.503**	-.026	.039	-.103	.051
Second. Contr. Factor	Other	Equal variances not assumed	34.017	.000	-2.835	259.505	**.005**	-.098	.035	-.166	-.030
Item Hit	Bridge/Structure	Equal variances assumed	1.464	.228	-.603	233	**.547**	-.016	.026	-.068	.036
Item Hit	Culvert	Equal variances not assumed	7.260	.008	-1.337	177.069	**.183**	-.025	.019	-.062	.012
Item Hit	Driveway/Embankment	Equal variances assumed	.031	.861	-.088	233	**.930**	-.006	.065	-.134	.123
Item Hit	Guardrail	Equal variances not assumed	7.921	.005	1.374	168.191	**.171**	.026	.019	-.011	.064
Item Hit	Submerged/Water	Equal variances assumed	.007	.935	.041	233	**.967**	.001	.026	-.051	.053
Item Hit	Tree	Equal variances assumed	1.902	.169	.692	233	**.489**	.042	.061	-.078	.162
Item Hit	Utility Pole	Equal variances not assumed	4.504	.035	-1.055	221.006	**.293**	-.033	.031	-.093	.028
Item Hit	Other	Equal variances assumed	.440	.508	.331	233	**.741**	.010	.030	-.049	.069
System Class	US Route Trunk Highway	Equal variances not assumed	7.276	.007	1.309	240.560	**.192**	.034	.026	-.017	.084
System Class	MN Trunk Highway	Equal variances assumed	3.588	.059	-.940	288	**.348**	-.044	.047	-.137	.049
System Class	CSAH	Equal variances assumed	.085	.771	-1.397	288	**.163**	-.082	.059	-.198	.034
System Class	MSAS	Equal variances not assumed	8.031	.005	1.369	232.467	**.172**	.033	.024	-.014	.080
System Class	County Road	Equal variances not assumed	12.276	.001	1.700	250.301	**.090**	.061	.036	-.010	.132
System Class	Municipal/Township/Other	Equal variances assumed	.003	.958	-.027	288	**.979**	-.001	.036	-.072	.070
Traffic Volume Range (ADT)	0 - 200	Equal variances assumed	1.306	.254	.571	288	**.568**	.022	.038	-.054	.098
Traffic Volume Range (ADT)	201 - 400	Equal variances assumed	3.016	.084	-.862	288	**.389**	-.036	.042	-.120	.047
Traffic Volume Range (ADT)	401 - 1,000	Equal variances assumed	.865	.353	.468	288	**.640**	.026	.055	-.082	.134
Traffic Volume Range (ADT)	1,001 - 2,000	Equal variances assumed	.015	.902	.062	288	**.951**	.003	.046	-.088	.094
Traffic Volume Range (ADT)	2,001 - 3,000	Equal variances assumed	.034	.853	.093	288	**.926**	.003	.032	-.060	.066
Traffic Volume Range (ADT)	3,001 - 5,000	Equal variances assumed	1.372	.242	-.584	288	**.560**	-.018	.031	-.080	.043
Traffic Volume Range (ADT)	5,001 - 10,000	Equal variances assumed	2.634	.106	.809	288	**.419**	.019	.023	-.027	.065
Traffic Volume Range (ADT)	10,001 - 15,000	Equal variances assumed	1.903	.169	.688	288	**.492**	.008	.012	-.015	.032
Traffic Volume Range (ADT)	15,001 - 20,000	Equal variances not assumed	11.173	.001	-1.743	153.000	**.083**	-.019	.011	-.042	.003
Traffic Volume Range (ADT)	20,001 +	Equal variances assumed	3.578	.060	-.940	288	**.348**	-.006	.007	-.020	.007

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